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ORIGINAL RESEARCH

A COMPARATIVE STUDY OF PASSIVE SHOULDER ROTATION RANGE OF MOTION, ISOMETRIC ROTATION STRENGTH AND SERVE SPEED BETWEEN ELITE TENNIS PLAYERS WITH AND WITHOUT HISTORY OF SHOULDER PAIN

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ABSTRACT

Background: Glenohumeral internal rotation deficit and external rotation strength have been associated with the development of shoulder pain in overhead athletes.

***Objective*:** To examine the bilateral passive shoulder rotational range of motion (ROM), the isometric rotational strength and unilateral serve speed in elite tennis players with and without shoulder pain history (PH and NPH, respectively) and compare between dominant and non-dominant limbs and between groups.

***Study Design*:** Cohort study.

***Methods*:** Fifty-eight elite tennis players were distributed into the PH group (n = 20) and the NPH group (n = 38). Serve velocity, dominant and non-dominant passive shoulder external and internal rotation (ER and IR) ROM, total arc of motion (TAM: the sum of IR and ER ROM), ER and IR isometric strength, bilateral deficits and ER/IR strength ratio were measured in both groups. Questionnaires were administered in order to classify characteristics of shoulder pain.

***Results*:** The dominant shoulder showed significantly reduced IR ROM and TAM, and increased ER ROM compared to the non-dominant shoulder in both groups. Isometric ER strength and ER/IR strength ratio were significantly lower in the dominant shoulder in the PH group when compared with the NPH group. No significant differences between groups were found for serve speed.

***Conclusion*:** These data show specific adaptations in the IR, TAM and ER ROM in the dominant shoulder in both groups. Isometric ER muscle weakness and ER/IR strength ratio deficit appear to be associated with history of shoulder injuries in elite tennis players. It would be advisable for clinicians to use the present information to design injury prevention programs.

***Level of evidence*:** 2

***Key words*:** Isometric strength, range of motion, serve speed, shoulder injury, tennis

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INTRODUCTION

High-performance tennis is a stressful game for the body, as it requires multiple repetitions of large ranges of motion (ROM) and high forces during strokes and movements around the court.[1] Because of the repetitive nature of tennis, the glenohumeral joint is often injured through overuse, especially in competitive elite tennis players. In this regard, the incidence of tennis injuries is approximately 21.5 injuries per 1000 practice hours.[2,3] Specifically shoulder complex injuries range between 25 and 47.7% of all injuries in the upper extremity for tennis players.[1,2] Several anatomical and mechanical adaptations are associated with an increased injury risk in the tennis player's shoulder, including asymmetries in dominant shoulder rotational passive ROM[4,5] and strength imbalance between the agonist/antagonist muscles of the glenohumeral joint (i.e., internal rotator (IR) and external rotator (ER) muscles).[4,6,7] Several previous researchers have shown that shoulder ROM is modified as an adaptive response to tennis play,[5,8,9] resulting in greater glenohumeral ER ROM, lower glenohumeral IR ROM and lower total arc of motion (TAM) of the dominant shoulder compared to the non-dominant shoulder.[4-6,8-10]

A glenohumeral IR deficit (GIRD) of the dominant shoulder compared to the non-dominant shoulder is considered a major risk factor for glenohumeral joint injury in overhead athletes as it causes imbalance in the soft tissues and could lead to shoulder instability[11,12], resulting in subacromial impingement syndromes and labral tears.[13] However, few studies have analyzed the relationship of asymmetries in shoulder rotation ROM and the shoulder pain history in tennis players, and these have shown different results.[4-6,10,14] For example, while several authors have reported no relationship between GIRD and pain in the dominant shoulder in players of different levels (i.e., junior, amateur and professional),[5,6,14] the authors of two studies found significant relationships in amateur[4] and professional players.[10]

In addition to shoulder ROM, strength of the shoulder rotator cuff muscles seems to be essential in order to dynamically stabilize the joint.[15] In overhead athletes[15] and healthy tennis players,[6,7,16-18] shoulder muscle imbalance and side to side differences between shoulders often occurs as the result of an adaptation to frequent overhead motions.[15] Several authors reported significantly greater IR strength[6,7,16,19] and lower ER/IR ratio[6,16] in the dominant shoulder in asymptomatic tennis players compared to the non-dominant shoulder. In uninjured elite tennis players, the recommended ER/IR strength ratio ranges between 61-76%, meaning that ER should have at least 2/3 of the IR strength.[16] In this regard, a muscle imbalance in the ER/IR ratio together with weak ER in the dominant shoulder have been associated with a high risk of shoulder pain in overhead athletes,[20-22] including tennis players.[4] However, the studies regarding shoulder rotation strength (measured using hand held dynamometry) in tennis players are scarce.[23] In addition, to the authors' knowledge, only a single previous study analyzed the relationship between ER/IR strength ratio and shoulder pain history in amateur tennis players.[4]

IR and ER strength of the shoulder muscles has also been related to performance in tennis, more specifically with serve speed, considered the most important shot in competitive tennis.[24] In this regard, Baiget et al[25] observed a relationship between shoulder IR isometric strength levels and serve speed. Moreover, previous authors have found a relationship between ball velocity and elbow and shoulder injuries in baseball players.[26,27] It has been suggested that an effective energy flow during the serve would allow the player to produce a high ball velocity,[28] but could also increase the mechanical load in the upper limb, thus leading to an increased risk of overuse injuries.[29] However, to the best of the authors' knowledge, no previous research analyzed the relationship between serve speed and shoulder pain in elite tennis players.

Thus, the aim of the present study was to examine bilateral passive shoulder rotation ROM, isometric rotation strength, the ER/IR isometric strength ratio and unilateral serve speed in elite tennis players with and without shoulder pain history (PH and NPH, respectively) and then compare these variables between dominant and non-dominant limbs and between PH and NPH groups. It was hypothesized that elite tennis players with PH would demonstrate reductions in IR ROM and TAM, and increases in ER ROM in the dominant shoulder. Moreover, players with PH would also show reduced isometric ER strength and lower ER/IR muscle strength ratios in the dominant shoulder compared to non-dominant limb and between the dominant limb of the NPH group. This information could identify possible deficits of the ROM, muscular strength imbalances and side to side differences between shoulders in the PH group and may help conditioning coaches and clinicians to design specific injury prevention interventions.

METHODS

Participants

A total of 58 male elite tennis players recruited from 10 different high-performance Spanish academies volunteered to participate in the study (Table 1). All the players participated in ~17 h of combined training (i.e., on and off-court) per week. Fifty-seven (98.2%) players were right-handed and one (1.7%) was left-handed. Furthermore, fifty-five (94.8%) players used a two-handed backhand for stroke.

The inclusion criteria were: subjects had to be healthy and actively competing at the time of the study, have no recent shoulder injury or surgery and not have taken any type of medication for the treatment of pain or musculoskeletal injuries at the time of the study. Furthermore, all players with PH had to be diagnosed by a specialist using ultrasound or magnetic resonance imaging. Exclusion criteria included players with pain and a positive Hawkins or Jobe´s test.[30] Written informed consent was obtained from each participant prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethic Committee of the University.

Based on the Consensus statement on epidemiological studies of medical conditions in tennis defined by Pluim et al and Fuller et al in soccer, the tennis players were divided into two groups: a) NPH group, which included 38 individuals who had not experienced shoulder pain; b) PH group, which included 20 tennis players who had experienced shoulder pain that had prevented them from training and/or competing in the 12 months prior to the study (mean time from injury to testing 4.49 ± 2.06 months) and had no pain history in the two months prior to the study. Five male players were excluded from the study because they reported shoulder pain during the recording session. Groups were compared with an independent measures t-tests, and there were no significant differences for age, height, mass, years of tennis practice, or hours of training per day (Table 1).

Procedure

All data collections were performed during the preseason months of October-December of 2013. Testing was performed during the athlete's off-season with at least one day of rest from playing tennis. Tests included three glenohumeral measurements for each IR and ER passive ROM and IR and ER isometric muscle strength test. Moreover, the serve speed during 10 maximum serves was also recorded. All assessments were conducted by the same two researchers: a first examiner conducted all tests (>15 years' experience), and a second one (8 years' experience) ensured proper participant positioning throughout the assessments. A week before the testing session, players performed a familiarization session to reduce the influence of learning on the measurements. Prior to testing all participants performed a five min warm-up, including forward/backward movements, sidestepping, and general mobilization (i.e., arm circles, leg kicks), followed by standardized dynamic stretching exercises (i.e., three sets of ballistic exercises with a 15 s rest period between each set and 15 repetitions

Table 1. *Descriptive characteristics (mean ± standard deviation) of the tennis players organized by group.*

	All tennis players (N = 58)	NPH (N = 38)	PH (N = 20)	t	p
Age (years)	20.7 ± 4.9	20.9 ± 5.3	20.2 ± 4.3	0.469	0.641
Mass (kg)	73.2 ± 8.8	73.2 ± 9.2	73.1 ± 8.1	0.043	0.966
Height (cm)	181.3 ± 6.5	180.5 ± 7.0	182.9 ± 5.2	-1.397	0.168
BMI (kg/m^2)	22.2 ± 1.7	22.4 ± 1.6	21.8 ± 2.0	1.182	0.242
Tennis experience (years)	12.8 ± 5.7	13.4 ± 5.9	11.6 ± 5.3	1.138	0.260
Training volume (h/week)	17.0 ± 3.0	16.8 ± 2.9	17.4 ± 3.2	-0.767	0.447

Independent measures t-test with between-subject factor with 2 levels (without history of shoulder pain (NPH) and with shoulder pain (PH)).

of flexion/extension, abduction/adduction and rotation dynamic stretching exercises.[33] All measurements were performed in a randomized and counterbalanced order for both, dominant and non-dominant shoulder. Shoulder measurements and serve speed were performed in the morning prior to training. Before the warm-up and stretching, players fulfilled a questionnaire regarding medical history. Finally, participants performed the rotational ROM test, followed by the serve speed and shoulder strength tests.

Measurements

Questionnaire

Participant's characteristics such as age, upper and lower limb dominant side, years of tennis practice, training volume (i.e., hours per week), and characteristics of the injuries reported were documented. The questionnaire also included a visual analogue scale (VAS) for pain evaluation. In the present study, shoulder pain was defined according to Pluim et al,[2] and Fuller el al.[32] Specifically, any injury case included in the data analysis was operationally defined as *"a physical complaint or manifestation sustained by a player that results from a tennis match or tennis training and led to an absence of the next training session or match"*.[31,32]

Shoulder ROM test

Passive shoulder IR and ER ROM (Fig. 1a, 1b, respectively) were measured with a manual inclinometer (ISOMED inclinometer, Portland, Oregon) of the dominant and non-dominant limbs, with the player in supine on a bench with the shoulder abducted 90 degrees (°) and elbow flexed to 90°. The inclinometer was placed approximately in the mid-point of the distal end of the forearm (for the IR and ER ROMs). The forearm was placed and remained in a pronated position for the duration of the testing. From this starting position, a researcher held the participant's proximal shoulder region (i.e. clavicle and scapula) against the bench to stabilize the scapula while rotating the humerus in the glenohumeral joint to produce maximum passive IR and ER. The end of IR and ER was defined as the point at which the scapula was felt to move following the methodology described by Clarsen et al.[22] Three maximal trials of each IR and ER ROM test for each limb were recorded and the mean score for each test was used in the subsequent analyses.

Shoulder strength test

Measurements of shoulder ER and IR strength were obtained with a hand-held dynamometer (HHD) (Nicholas Manual muscle test, Co, Lafayette IN; range 0–500 N, sensitivity 0.2 N) in a supine position on the bench with the arm in 90° of abduction and 0° of rotation, in the scapular plane[18] (Fig. 2a and 2b). The elbow was flexed in 90° and the examiner stabilized the humerus by pressing it down toward the bench. The testing angle was checked by visual inspection. For ER strength, the player externally rotated the shoulder against the HHD, while the HHD was located proximal to the ulnar styloid process (Fig. 2a). For IR strength, the player internally rotated the shoulder, against the HHD, while

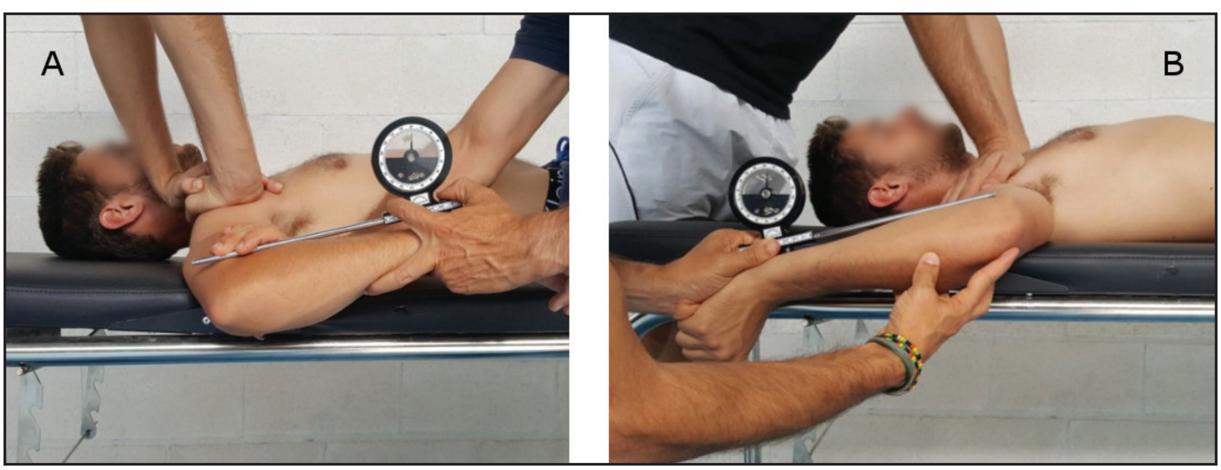

Figure 1. *Assessment of the shoulder rotation range of motion: A) testing for glenohumeral internal rotation position; B) testing for glenohumeral external rotation position.*

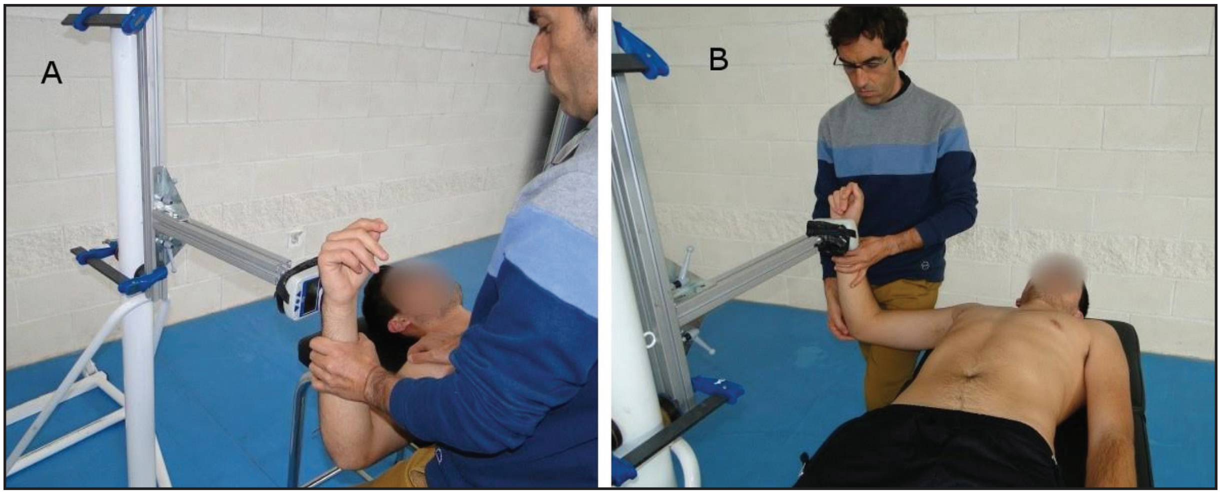

Figure 2. *Assessment of the isometric shoulder rotation strength: A) testing for shoulder maximal isometric external rotation strength; B) testing for shoulder maximal isometric internal rotation strength.*

the HHD was located proximal to the radius styloid process (Fig. 2b). According to Saccol et al,[15] the dynamometer was maintained fixed to a structure with wall support in order to avoid any interference in the stabilization. The isometric strength test consisted of three ER and IR repetitions of a 5 s maximal effort, with 30 s rest between each trial. The peak of each repetition was considered. The mean of the three repetitions was calculated and normalized with respect to each subject's body mass and was used to assess ER, IR strength and ER/IR strength ratios. The HHD was calibrated according to the manufacturer's specifications prior to each test.

Serve speed

Speed reached in the serve tests were used as an ecological proxy for upper extremity power. The serve speed was measured by a radar gun (model SR3600, Homosassa, FL, USA; range 80 to 232 km/h, sensitivity $\pm$ 0.44 m/s). The radar gun was set on "Peak mode" to detect maximal ball speed. Before each experimental session, the radar gun was calibrated in accordance with the manufacturer's specifications. The radar was positioned on the center of the baseline, 4 m behind the server, aligned with the approximate height of ball contact ($\sim$ 2.2 m) and pointing down the center of the court. After a brief warm-up for the joints involved in the service motion (i.e., dynamic movements in the shoulder, plus five slow services), each player served 10 serves to the advantage court with a 30 s rest between each of them. To be accepted, serves had to fall into the service box. The highest speed recorded was used for further analyses.

Statistical analysis

Descriptive statistics (means and standard deviations) for each of the variables of shoulder flexibility, shoulder strength and serve speed were calculated. Normality of the data distribution was verified using the Kolmogorov-Smirnov test.

Two-way mixed-design ANOVAs were performed to explore the differences in the dependent variables. A within-subject factor (side: dominant and non-dominant) and a between-subject factor (pain group: NPH and PH) and their interactions were included in the model. A Levene's test for equality of variances was used to assess homogeneity of variances, and showed no differences in any of the measured variables. Effect sizes for ANOVAs are reported as partial omega squared calculated according to Lakens and interpreted as small, medium, and large, corresponding to values of 0.010, 0.059, and 0.138 respectively.[35]

As a post-hoc comparison, a related measures t-test was conducted to identify differences in the shoulder's ROM and strength between dominant and non-dominant limbs. An independent measures t-test was conducted to compare between groups.

To determine the magnitude of differences between the groups or limbs for each variable, effect sizes and their 95% confidence intervals were calculated using standardized mean difference corrected as Hedges' g_s.[34] The following interpretation of g_s was used: 0.4 or less small; between 0.4 and 0.7 moderate; greater than 0.7 large.[35]

All analyses were performed using the SPSS package (version 18, SPSS Inc., Chicago, IL, USA) and a custom-made Excel sheet was used to calculate the effect sizes. The level of significance chosen was $p < 0.05$. In addition, a comparison was considered statistically significant when the effect size confidence interval did not cross the zero value.

RESULTS

Characteristics of the participants are outlined in Table 1. Thirty-eight players (65.5%) did not suffer shoulder injuries during the previous season, and the remaining (34.4%) sustained 20 tendinopathies (3 biceps brachii and 17 supraspinatus), and all began with an overuse onset. In terms of severity, one was a mild injury (lasting 4–7 days), 10 were moderate injuries (8–28 days) and 9 were severe injuries (> 28 days). Specifically, 16 of the injuries (80%) occurred during match play and 4 (20%) during practice. There were no significant differences between groups with regard to descriptive characteristics, years of tennis practice, or hours of training per day (Table 1).

Table 2 displays the results of the ROM, isometric strength and serve speed measurements, including the within-subject comparisons (i.e. between dominant and non-dominant shoulders), and the between subject comparisons (i.e. dominant shoulder of each group). The two-way mixed-design ANOVA showed an interaction effect between the factors side*pain in the ER isometric strength ($F(1, 54) = 12.520$, $p = 0.001$, $\omega_p^2 = 0.171$) and in the ER/IR isometric strength ratio ($F(1, 54) = 5.424$, $p = 0.024$, $\omega_p^2 = 0.073$). There is also a main effect in the between-subjects factor in ER isometric strength ($F(1, 54) = 4.361$, $p = 0.042$, $\omega_p^2 = 0.057$) and in the strength ratio ($F(1, 54) = 11.368$, $p = 0.001$, $\omega_p^2 = 0.156$). The within-subjects factor shows a main effect in all the variables ($p < 0.001$, $0.179 < \omega_p^2 < 0.715$).

In the within-subject comparison, the PH and NPH groups presented significantly lower values of IR ROM (effect size 1.16 [0.50, 1.82] and 1.55 [1.04, 2.06] respectively, $p < 0.01$), and of TAM (.49 [-0.04, 1.01], $p < 0.05$ and .45 [0.09, 0.80], $p < 0.01$, respectively), but higher ER ROM (-0.77 [-1.34, -0.19], $p < 0.05$ and -0.97 [-1.39, -0.56], $p < 0.01$, respectively) on the dominant side (Fig. 3a).

Furthermore, PH and NPH players showed lower ER/IR isometric strength ratios (1.16 [0.48, 1.85], $p < 0.01$ and .38 [0.02, 0.73], $p < 0.05$, respectively) and higher IR isometric strength (-0.58 [-1.12, -0.04] and -.75 [-1.14, -0.36] respectively, $p < 0.01$) in the dominant side compared with the non-dominant side (Fig. 3b). The NPH group also had significantly higher ER isometric strength in the dominant side compared with the non-dominant side (-0.59 [-0.96, -0.21], $p < 0.01$).

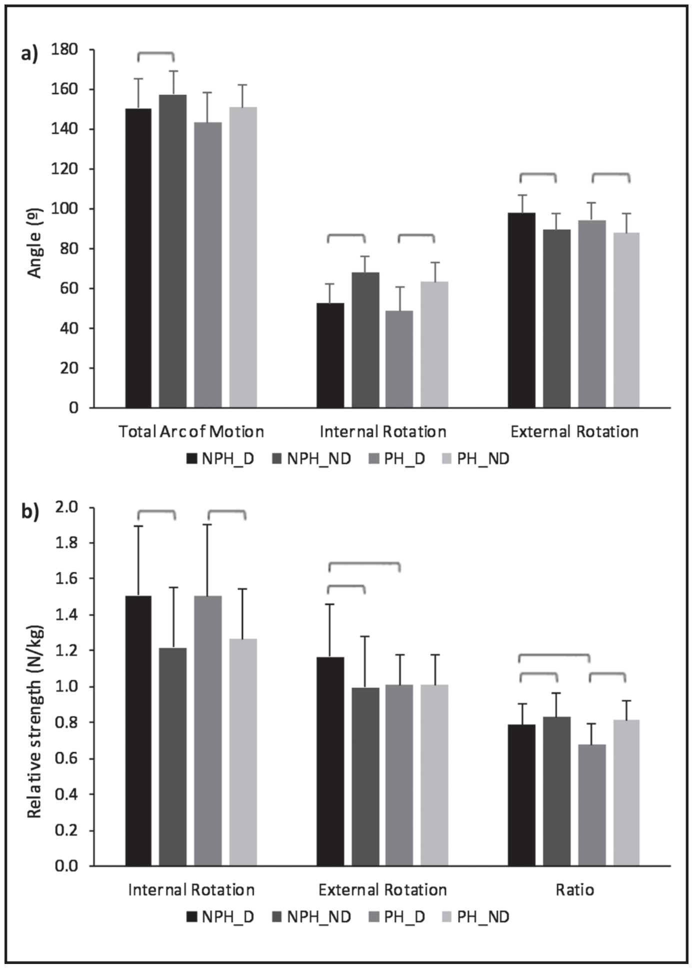

Figure 3. *Range of motion (a) and strength (b) in the injured (dominant or D) and non-injured (non dominant or ND) limbs in both pain history (PH) and no pain history (NPH) groups (brackets denote p < 0.05 and effect size confidence interval out of zero).*

Table 2. *Average ± standard deviation of the different glenohumeral rotation ROM (º), isometric strength relative to body mass (N/kg) and serve speed (km/h) comparing between subjects with no pain history (NPH) and with pain history (PH), and within-subject dominant and non-dominant sides in both groups.*

Variables	NPH (N = 38)	PH (N = 20)	p	ES [95% CI]
Total arc of motion (º)				
Dominant	150.3 ± 14.9	143.1 ± 15.1	.089	0.47 [-.09, 1.03]
Non-dominant	157.1 ± 12.0	150.8 ± 11.2	.055	0.53 [-.03, 1.10]
Diff	6.8 ± 12.1	7.7 ± 12.2	.807	-0.07 [-.62, .49]
Within-subject comparison p, ES [95% CI]	.001, 0.45 [.09, .80] *	.011, 0.49 [-.04, 1.01]		
Internal rotation ROM (º)				
Dominant	52.5 ± 9.7	48.7 ± 12.0	.204	0.35 [-.21, .91]
Non-dominant	67.8 ± 7.9	63.2 ± 9.7	.056	0.53 [-.03, 1.09]
Diff	15.3 ± 9.2	14.5 ± 8.8	.728	0.10 [-.46, .65]
Within-subject comparison p, ES [95% CI]	.000, 1.55 [1.04, 2.06] *	.000, 1.16 [.50, 1.82] *		
External rotation ROM (º)				
Dominant	97.8 ± 8.5	94.4 ± 8.5	.151	0.40 [-.16, .95]
Non-dominant	89.3 ± 8.3	87.6 ± 9.5	.476	0.20 [-.36, .75]
Diff	-8.5 ± 7.4	-6.8 ± 9.5	.454	-0.21 [-.76, .35]
Within-subject comparison p, ES [95% CI]	.000, -0.97 [-1.39, -.56] *	.005, -0.77 [-1.34, -.19] *		
Relative internal rotation strength (N/kg)				
Dominant	1.51 ± 0.38	1.50 ± 0.40	.953	0.02 [-.54, .57]
Non-dominant	1.22 ± 0.34	1.26 ± 0.28	.610	-0.14 [-.70, .42]
Within-subject comparison p, ES [95% CI]	.000, -0.75 [-1.14, -.36] *	.001, -0.58 [-1.12, -.04] *		
Relative external rotation strength (N/kg)				
Dominant	1.17 ± 0.29	1.01 ± 0.17	.028	0.62 [.05, 1.19] †
Non-dominant	1.00 ± 0.29	1.01 ± 0.17	.848	-0.05 [-.61, .50]
Within-subject comparison p, ES [95% CI]	.000, -0.59 [-.96, -.21] *	.999, 0.00 [-.49, .50]		
External rotation/Internal rotation strength ratio				
Dominant	0.79 ± 0.12	0.68 ± 0.11	.001	0.94 [.34, 1.53]
Non-dominant	0.83 ± 0.13	0.81 ± 0.11	.643	0.13 [-.43, .68]
Within-subject comparison p, ES [95% CI]	.037, 0.38 [.02, .73] *	.001, 1.16 [.48, 1.85] *		
Serve speed (km/h)				
Dominant	167.9 ± 11.7	171.6 ± 12.4	.273	-0.30 [-.86, .25]

ES = Effect size [95% confidence limits]; Diff = difference between shoulders (non-dominant – dominant).
* and † Statistically significant within-subject and between groups difference respectively (p < 0.05 and effect size confidence interval out of zero).

The magnitude of side to side between groups comparison showed significant differences between the PH and NPH groups. Especially the PH group showed significantly lower ER and ER/IR isometric strength ratio in the injured side (dominant) compared with the dominant side in NPH players (0.62 [0.05, 1.19], $p < 0.05$ and 0.94 [0.34, 1.53], $p < 0.01$, respectively). In contrast, the comparison of serve speed showed no differences between groups (-0.30 [-.86, 0.25], $p > 0.05$).

DISCUSSION

Several authors have suggested that competitive tennis leads to alterations in IR ROM and shoulder rotation muscle strength imbalances (i.e., ER/IR ratio modifications), which may be a contributing factor to shoulder injuries.[7-9] However, the association between shoulder injury and decreased rotational ROM, as well as strength imbalance and performance (i.e., serve speed) has not been widely analyzed previously in elite tennis players. Results obtained in the present study reported significant side to side differences in shoulder rotation ROM and isometric strength in elite tennis players with PH and NPH. Despite both groups showing important adaptations in the dominant shoulder, isometric ER strength and ER/IR strength ratio were significantly lower in the dominant shoulder in the PH players when compared with the NPH players.

The current results showed reductions in IR ROM and TAM, and increases in ER ROM in the dominant shoulder compared to the non-dominant side, which are in line with previous results obtained both in uninjured tennis players[4-6,8,14] and in injured tennis players.[4,5] These asymmetric rotational ROM have been considered specific adaptations in tennis players caused by the high repetitive loading forces generated by strokes, mainly the serve and groundstrokes.[36] Also, the findings of the current study are in line with those of previous researchers who did not observe significant differences between the NPH and PH groups for the side-to-side asymmetries in glenohumeral rotation ROMs in players with different levels (i.e., professional,[5] amateur[6] and junior[14]). However, these results differ from two previous studies[4,10] reporting significant differences between PH and NPH players in the side to side IR. The lack of agreement between studies could be related to the differences among protocols[10] or participant's characteristics, as in the present study the PH group was "healthy" at the time of the study, while the group analyzed in the study of Marcondes et al[4] presented with shoulder pain at the time of the study. It is therefore logical to speculate that the presence of pain could alter the results of rotation ROM measures. Another possible explanation for these discrepancies can be related to the age differences in the participants, with previous studies analyzing players ranging between 19 and 33 years old (i.e., 26.2 $\pm$ 3.9 years), while in the present study players averaged 20.7 $\pm$ 4.9 years. In this regard, previous research analyzed IR ROM differences in the shoulders of players with different ages, highlighting a progressive decrease as age increases.[5,9,18] In addition, in the present study, non-dominant shoulder in the PH group showed less glenohumeral IR (63.2°) and TAM (150.8°) than the NPH group (IR = 67.8°; TAM = 157.1°), although the differences did not reach statistically significant. These findings partially agree with the results reported by Moreno-Pérez et al in professional tennis players, which showed significantly less glenohumeral IR (in both shoulders) and TAM (in the non-dominant shoulder) than the NPH group. Perhaps, the small discrepancy might be due to participant age differences in the PH group; the current study had an average age in PH group of 20.2 $\pm$ 4.3 years, while in that of Moreno-Pérez et al it was 25.6 $\pm$ 3.0 years. Furthermore, in the study by Moreno-Pérez et al the years of tennis experience in the PH group (17.6 $\pm$ 6.0) were very different from the experience in the present sample (11.6 $\pm$ 5.3), which could affect results between groups.

Concerning the shoulder rotator muscle strength, previous studies conducted with tennis players,[4,19] and other overhead athletes[20-22] have demonstrated similar significant results regarding higher IR isometric strength and decreased ER/IR isometric strength ratio in the dominant shoulder compared with the non-dominant side in uninjured and injured athletes. Increases in IR strength are likely due to the high demands imposed on these muscles during tennis strokes, especially the forehand and the serve, which can account for approximately 80% of the total number of strokes during a match.[37] In addition, the repetitive high demands on IR strength in the dominant side during tennis strokes may increase the tensile stress on the posterior rotator cuff and scapular stabilizers, and could develop a strength imbalance between the ER and IR over time.

Interestingly, the PH group had reduced dominant ER strength and ER/IR isometric muscle strength ratio in the injured side compared with the dominant side in NPH players. These results support previous studies conducted in a population of baseball[20,21] and handball[22] players with shoulder injuries, whose authors reported a relationship between ER weakness and decreased ER/IR muscle strength ratio (measured with HHD). This suggests that a weakness in ER strength is associated with imbalance between the propulsive IR during throwing or serving and the ER muscles responsible for deceleration and stabilization of the shoulder during these sports actions. Therefore, poor ER strength may increase the risk of shoulder injury, and strength training, which aims to enhance strength of the ER muscles, and may contribute to reducing the risk of a future shoulder injury.

Several authors that have studied overhead sports believe that increasing IR strength of the dominant shoulder without simultaneously increasing ER strength would produce an imbalance that could possibly lead to higher injury risk.[22,38] However, very few studies have specifically analyzed the relationship between shoulder injuries and strength ratio with HHD in tennis players.[4] The present results were similar to those of Marcondes et al. who found that ER/IR strength ratio was a mean of 0.82 in the dominant shoulder in uninjured players and of 0.74 in the injured group. However, in the present study, a mean of 0.68 and 0.79 rotational strength ratio in the dominant side in the injured and uninjured players was found, respectively. The lower difference between studies could be due to differences in the demands of training and competition (intensity, duration, frequency, etc.) because while the sample of Marcondes et al played between 8 and 12 hours per week (training or playing), the players analyzed in the current study played an average of 17 hours per week. Probably the higher IR strength obtained in data in both shoulders would explain a greater imbalance between the ER/IR muscle strength ratio. Future research involving tennis players needs to be carried out to elucidate the effects of different training and competition demands on the strength and the risk of shoulder pain.

Regarding serve speed, the results showed no differences between groups. In the serve's kinetic chain, shoulder IR is the joint movement with the highest speed before ball impact.[39] Present data showed no between group differences in IR strength, so it is not surprising that the serve speed remained similar. On the contrary, as stated before, the reduced ER strength presented in the PH group should increase injury risk when decelerating shoulder rotation in the follow-through phase, emphasizing the necessity of shoulder strengthening (i.e., ER focused) programs performed by the players.

Based on the present results, players who have suffered shoulder pain within the year prior to the study may continue to have a strength deficit after the injury has abated. Therefore, preventative strengthening of the shoulder ER muscles would be recommended and should be an integral part of a tennis player's conditioning and injury prevention program with the aim of avoiding future recurrences. However, future studies should determine if such a strengthening program does, indeed, result in reduced shoulder re-injury.

While the results of this study have provided information regarding the relationship between passive shoulder ROM, isometric strength and serve speed in elite tennis players with and without shoulder pain history, limitations to the study must be acknowledged. The evaluation of players was performed cross-sectionally. While it would be beneficial to analyze elite tournament players in a longitudinal study, it is logistically difficult due to their geographic mobility and uncertain future career paths. Similarly, a post-injury cross-sectional study informs us about the condition of athletes deemed recovered from a shoulder injury, which is valuable information as to their physical condition after they return to play. However, the post-injury rehabilitation programs undergone by the players with shoulder pain were neither controlled or investigated, and may have modified the outcomes of this study.

CONCLUSION

The results of the present study revealed significantly lower isometric ER strength and reduced ER/IR muscle strength ratios in the dominant shoulder in elite tennis players with a history of shoulder pain when compared with NPH players. Furthermore, regarding the side to side asymmetries, the dominant shoulder in both groups reported adaptations of shoulder ROM, with reduction of the IR and TAM, and an increase in the ER ROM when compared with the non-dominant side. Additionally, the dominant limb showed higher IR isometric strength and decreased ER/IR isometric muscle strength ratio in the PH and NPH group. Understanding the tennis-specific adaptations of the shoulder complex could help tennis players, coaches, athletic trainers, and clinicians to design and utilize optimal exercise protocols, both preventatively and post-injury for players who had suffered shoulder pain within the previous year.

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